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Procedia - Social and Behavioral Sciences 223 (2016) 720 – 725
Procedia Social and Behavioral Sciences

2nd International Symposium "NEW METROPOLITAN PERSPECTIVES" - Strategic planning, spatial planning, economic programs and decision support tools, through the implementation of Horizon/Europe2020. ISTH2020, Reggio Calabria (Italy), 18-20 May 2016

Rooftop Gardening. A Solution for Energy Saving and Landscape Enhancement in Mediterranean Urban Areas

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Abstract

Urban green areas are losing their exclusively aesthetic and scenic significance and are increasingly acquiring a social value related to a return to the ancient rural traditions characterizing the history of peoples. Rooftop gardening is therefore an opportunity to grow agricultural crops rather than decorative plants. However, according to the scientific literature, it is also an optimal solution for the passive control of indoor microclimate conditions, above all in hot climate areas. The shade contribution, the evapotranspiration effect of plants and the thermal inertia of the growing medium allow limiting the summer solar load in the building. The goal of this study is to evaluate the effects of a rooftop garden in an urban area. After choosing a horticultural crop suitable for rooftop gardening, the need for biomass thermal energy for the building air conditioning was evaluated in two different configurations: the one with a traditional flat roof, the other with a rooftop lettuce garden. The energy analysis of the building with the traditional roof showed that the consumption of the total biomass energy produced annually to keep the required indoor thermal conditions was about 15304 kW. That analysis also showed that, in the case of the rooftop lettuce garden, energy could be limited to about 12592 kW, which corresponds to a reduction of some 18% of the total annual energy.

Peer-review under responsibility of the organizing committee of ISTH2020

Keywords: Biomass; Buildings; Energy; Green roofs; Sustainability

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1877-0428
Peer-review under responsibility of the organizing committee of ISTH2020
doi:10.1016/j.sbspro.2016.05.248

1. Introduction

First records about rooftop gardening date back to ancient Etruria and Rome. Today, a few valuable examples of roof gardensremain in Italy, such as the Mausoleum of Augustus and Hadrian in Rome, Villa D'Este in Tivoli, the Belvedere Gardens in the Vatican and the Royal Palace in Naples. Other ancient roof gardens can be found scattered throughout Europe, e.g. the Palace of Versailles in Paris. In ancient times, roof gardens had merely aesthetic purposes or were used to parade the grandeur of a civilization. It was the German architect Von Rabitz, (Abram, 2006) who first spread the modern concept of rooftop gardening. In 1865, Von Rabitz wrote a treatise on the use of roof gardens as a means to make the environments, which were heavily affected by human activity, healthier. It was exactly in that period that green areaswere rediscovered not only for their aesthetic value but also for their social and health impacts. Since then, a slow and seesawing path has started, which has only recently led to the use of rooftop gardening for urban mitigation and compensation. Over time, “roof-gardens” have turned into "green roofs", "living roofs" or "eco-roofs".This evolution has been mainly driven by technological innovation in the structural and agronomic fields as well as in engineering. Green roofsare different from roof gardens since the latter are characterized by the presence of independent pots and planters placed on traditional covering, such as a terrace or a balcony. In contrast, in a green roof, the garden is made up of various layers of growing media and protective elements and covers the whole roof, with varying slope. The need to improve the environmental conditions in cities, the renewed interest in agriculture and the will to spend one's spare time cultivating a vegetable garden and growing agricultural products for family consumption have brought about a huge development of urban vegetable gardens, shared gardens, experimental cultivation of small gardens or green areas in big cities to produce vegetables. Urban green areas are losing their exclusively aesthetic and scenic significance and are increasingly acquiring a social value related to a return to the ancient rural traditions characterizing the history of peoples. Rooftop gardening is therefore an opportunity to grow agricultural crops rather than decorative plants. However, according to the scientific literature (Ascione, F., Bianco, N., De' Rossi, F., Turni, &Vanoli, G., 2013; Marrara, C.V., Barreca, F., & Di Fazio, S. , 2014; Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A., & Mihalakakouet, G., 2001; Silva, C. M., Gomes, M.G., & Silva, M., 2016), it is also an optimal solution for the passive control of indoor microclimate conditions, above all in hot climate areas. The shade contribution, the evapotranspiration effect of plants and the thermal inertia of the growing medium allow limiting the summer solar load in the building. The goal of this study is to evaluate the effects of a rooftop garden in an urban area. After choosing a horticultural crop suitable for rooftop gardening, the biomass thermal energy consumption for the air conditioning of the examined building will be evaluated in two different configurations: the one with a traditional flat roof, the other with a green roof.

2. Materials and Methods

Lettuce (*Lactuca sativa* L.) is certainly among the most popular horticultural crops which best adapt to the Mediterranean climate. It is a biennial, dicotyledonous angiosperm belonging to the Compositae family. It has a quite short main taproot, which usually grows down into the soil for 0.20-0.40 m or for over 0.80 m only in light and deep soils, and numerous secondary roots. During its growth, the stem extends forming a branched scape that can reach 20-130 centimetres of height. The brancheson the flowering stem end with heads of 15-25 yellow flowers. The colour of the leaves changes according to the type of lettuce, from more or less light green to purple red or white. Lettuce well adapts to any kind of soil, whether sandy or clayey, and though it is sensitive to high and low temperatures, it can be harvested throughout the year, if it is constantly watered and protected during the periods of highest thermal stress. The energy performances of a residential building located in the city of Reggio Calabria (lat. 38.07° long.15.65° asl: 21m) were analysed by means of advanced dynamic thermal analysis software (DesignBuilder©). The city has a typical Mediterranean climate with hot summers and mild winters (fig. 1). Two different types of roof were considered for the building. The one was a traditional roof made up of a reinforced-concrete floor with an EPS insulation layer; the other was a green roof. In particular, the second type of roof included a lettuce crop with a density of 15 plants/m^2, which corresponds to a distance of 20 cm between plants on the same row and of 30 cm between rows, and with a production of some 3 kg/m^2 per harvest. Moreover, it should be noticed that lettuce can be harvested several times a year if different species are used for each season. Table 1 shows the succession and the thermophysical characteristics of the layers composing the types of roof.

Table 1. Thermophysical characteristics of the layers composing the traditional roof (T) and the green roof (G)

Layer	Roof	Thickness [m]	Conductivity [$W \cdot m^{-1} \cdot K^{-1}$]
Lime sand	T/G	0.004	0.800
Reinforced concrete (steel 2%)	T/G	0.150	0.380
Polyurethane insulation	T/G	0.070	0.023
Bitumen sheet	T/G	0.400	0.230
Drainage	G	0.070	0.300
Filter	G	0.005	0.300
Growing medium	G	0.250	0.300

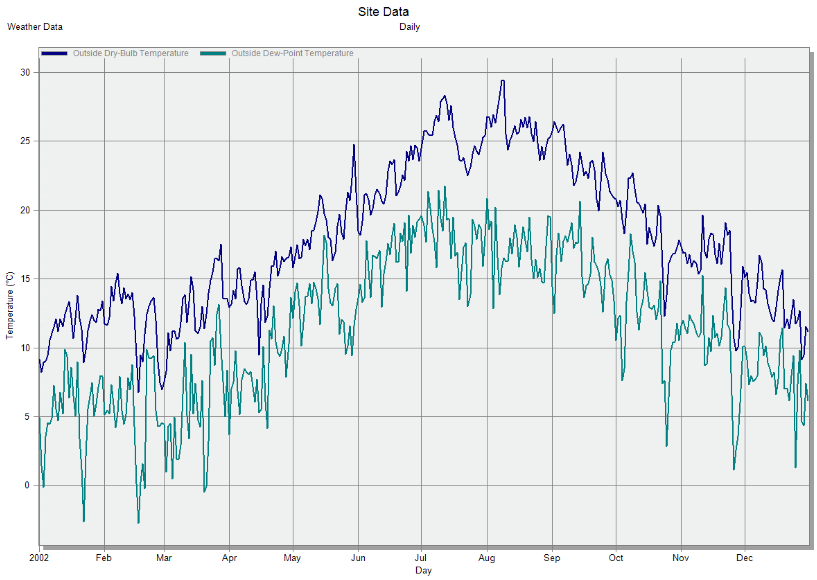
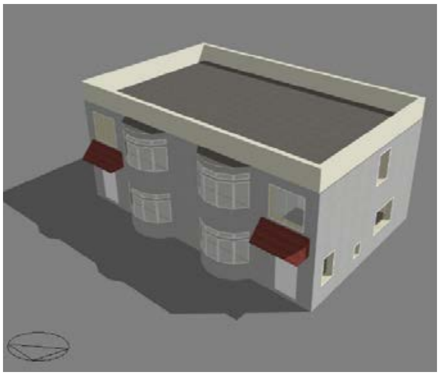


Fig. 1. Temperature pattern in the examined building

2.1. The reference building

The reference building is a typical urban semi-detached house (fig. 2 a,b). It is a two-storey building: on the ground floor is a living area with living room, kitchen and bathrooms; on the first floor are bedrooms and bathrooms. Walls are made up of 25 cm-thick perforated bricks with 3.5 cm-thick outer EPS coating and an internal 1.5 cm-thick layer of plaster for a final thermal transmittance value of 0.362 $W \cdot m^{-2} \cdot K^{-1}$, which complies with the decrees of the Italian Ministry for Economic Development of 26 June 2015. The roof consists in a reinforced-concrete floor whose internal side is covered with a layer of gypsum plaster. Such a layer is coated with an EPS insulation layer, which is protected from atmospheric agents by a tar felt sheet. The thermal transmittance U-value of the roof is 0.225 $W \cdot m^{-2} \cdot K^{-1}$ (Table 1). The building plan area is 99.23 m^2, while the total height measured to the second floor is 16 m. Indoor temperature is set between 18 and 25 °C, so that the heating system switches on for lower values, while the cooling system switches on for higher ones. Both systems are fuelled by biomass, with a COP equal to 0.5 in the heating phase and a COP equal to 1 in the cooling phase.

a)



b)

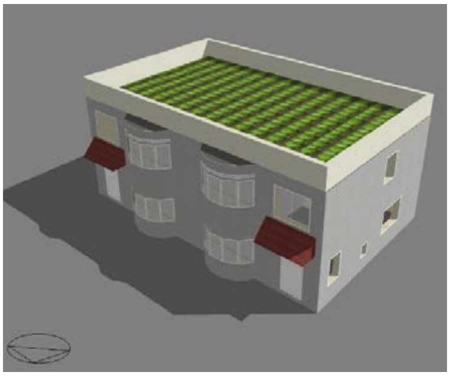


Fig. 2. (a) residential building with traditional roof; (b)residential building with green roof.

2.2. Rooftop garden

The growing medium for the lettuce crop is composed of a 25 cm-thick layer of topsoil lightened with expanded vermiculite and enriched with potassium, a fundamental element for lettuce growth but also characterized by a high drainage capacity. With a view to limiting the final thickness of the floor and the total weight of the soil, the drainage layer was built with propylene boards that, besides ensuring a proper drainage of the soil, allow accumulating water for periods when it is less readily available. It is necessary to place a filtering cloth between the soil and the drainagelayer in order to prevent granules from obstructing drainage holes. It is also suitable to position a rootbarrier to prevent roots from damaging the floor waterproofing.

2.3. Thermal analysis

The building thermal performances were analysed taking into account outdoor climate conditions throughout the year. The simulation considered the thermophysical characteristicsof the building envelope and, in particular, its heat capacity, which, depending on outdoor thermal variations, causes a phase lag of the thermal wave. This kind of analysis highlights particular computational difficulties, above all if a rooftop garden is present. An analysis model widely used by the international scientific community is the Fast All-Season Soil STrength model (FASST) (Frankenstein & Koenig, 2004) developed by the Army Corps of Engineers. It is based on two extensively tested models, the Biosphere Atmosphere Transfer Scheme (BATS) and the Simple Biosphere model (SiB), that enable to calculate the temperature on the surface of the growing medium and on the leaves.

The model was implemented within a specific module of the software Energy Plus developed by the US Department of Energy. Such software solves the system of linearized equations representing the complex processes of heat exchange between the vegetal layer, the layer of growing medium, the outdoor environment and the roofing system, by means of a method based on finite differences. The use of the software Energy Plus requires the construction of the physical model to analyse. Therefore, in this study, the software Design Builder was used to develop and analyse the case study. This internationally validated programme has a set of modules and functions that enable to pre- and post- process the models of the buildings to analyse.

The application of the calculation model requires a series of parameters related to both the vegetative characteristics of the plant and the physical conditions of the soil. Such data are not always easily available since there is no specific database in the literature, particularly as regards the plant species that are most commonly used or can be used on such roofs (Coma, J., Pérez, G., Solé C., Castell A.,.&Cabeza, L. F., 2016). As to the lettuce, in this study, a few data were taken from the scientific literature, while others were experimentally calculated or measured. Table 2 shows the values considered and their sources.

Table 2. Values of the quantities used in the thermophysical model of the green roof

Green Roof Data	Value	Source
Height of Plants [m]	0.17	measured
Leaf Area Index	5.00	measured
Leaf Reflectivity	0.40	(Brach E. J. *et al.*; 1982)
Leaf Emissivity	0.98	measured
Minimum Stomatal [s/m]	125.00	(Nakayama S.,1991)
Max volumetric moisture content of the soil layer (saturation)	0.50	calculated
Min (residual) volumetric moisture content of the soil layer	0.010	calculated
Initial volumetric moisture content of the soil layer	0.15	calculated

3. Results

The thermal insulation is the best solution for the energy saving in residential buildings or in agricultural buildings (Porto, S. M. C, Valenti, F., Cascone, G., & Arcidiacono, C. 2015).

The energy analysis of the building with the traditional roof showed that the consumption of the total biomass energy produced annually to keep the required indoor thermal conditions was about 15304 kW, around 13767 kW for cooling and 1537 kW for heating. Wood combustion and gasification are the main processes of converting the wood chemical energy into thermal energy (Proto, Zimbalatti, Abenavoli, Bernardi & Benalia, 2014). The hypothesis was that the energy for the cultivation of the lettuce was compensated with the production of vegetables.That analysis also showed that, in the case of the green roof, the energy required to air-condition the building was limited to about 12592 kW, of which some 11338 kW are needed for cooling and 1254 kW for heating. This result demonstrates that a rooftop garden, such as a rooftop lettuce garden, allows saving around 18% on the total annual energy. In particular, the highest annual energy saving occurs in the cooling phase, accounting for over 2400 kW.

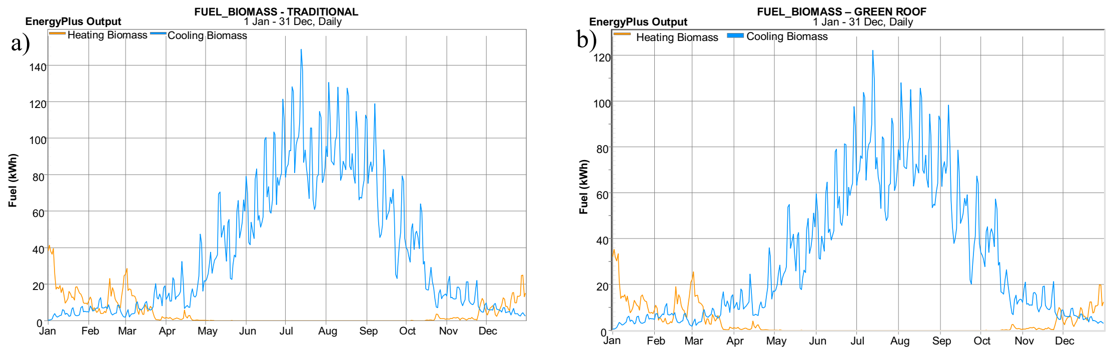


Fig. 3. Daily biomass energy consumption rate (a) Traditional roof); (b) Green roof.

4. Conclusions

The Green roofs are the most suitable solution for reducing the external roof surface temperature in any climate (Costanzo, V., Evola, G., Marletta, L. , 2016).

The advantagesof green roofsare clear, not only in terms of energy efficiency but also in terms of capture of CO_2, which is a serious environmental emergency in densely populated cities. Further advantagesof this solution are related to the heat island effect and to the rainwater retention brought about by an urban green area. This study shows that green roofs, and in this specific case a rooftop lettuce garden, lead to almost 18% saving a year on biomass energy as well as to significant landscape improvement, to CO_2 capture and to retention of rainwater, which is one of the most frequent causes of floods in big cities. However, the use of this kind of roof requires careful preliminary design since it is crucial to plan and construct all the roof components correctly. Malfunctioning of one element can irreparably undermine the whole system. Furthermore, particular attention should be paid to the increased structural loads this solution may entail. Actually, one of the elements that affect the implementation of this kind of solution also in existing buildings is the increased load per unit area deriving not only from the layer of growing medium but also from the water accumulation needed to feed plants. Nevertheless, the utilization of lightened growing media and more effective drainage systems enables to limit this weakness.

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